Evaluation of Calitoo Handheld Sun Photometer for Classroom Use

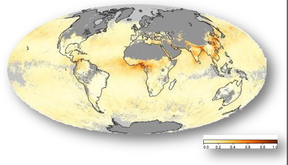
Cara Moulton[1]
Dr. Margaret Pippin[2]
[1]Sitting Bull College, Fort Yates, Standing Rock Reservation, [2]NASA Langley Research Center, Hampton, VA

Background

Atmospheric particles of liquids and solids, called aerosols, can have harmful effects on both animals and vegetation depending on their levels. Human activity is a cause of these harmful aerosol levels. Certain aerosol particulates effect ability to breathe. Currently satellites including MODIS, MISR, and TOMS measure aerosols by visible (nadir and multi-direction) and UV reflection, respectively. Ground-based measurements using handheld sun photometers can determine the presence of aerosols through solar voltage readings and aerosol optical depth calculation, allowing for many schools worldwide measure and submit atmospheric data through the Global Learning and Observation to Benefit the Environment (GLOBE) program. An important parameter measured by participating GLOBE schools is Aerosol Optical Thickness (AOT).

Locations of AOD measurements- GLOBE schools- since 2010 showing amount of measurements

https://www.globe.gov/



February 2010 MODIS satellite data, areas in grey indicate measurements lacking

http://modis.gsfc.nasa.gov/

Sun Photometer

GLOBE Sun Photometer:
Sun Voltage [505λ, 625λ]
Dark voltage
T_start [initial temperature]
T_end [final temperature]
Alternate Sources:
Date (UTC) Time (UTC)
Latitude (degrees)
Longitude (degrees)
Barometric pressure (mb)

AOT: Hand-calculated

GLOBE Sun Photometer

Calitoo

Calitoo Sun Photometer:
Date (UTC) Time (UTC)
Temperature (Celsius)
Pression [Air Pressure] (milibars)
Sun Voltage [619λ, 540λ, 465λ]
Altitude (unused)
Latitude (decimal)
Longitude (decimal)
Elevation (radians)
AOT [619λ, 540λ, 465λ]
CN0 [619λ, 540λ, 465λ]
Rayleigh scattering
Ozone [619λ, 540λ]

AOT: Automatic

Since 1998, the GLOBE program has relied on the GLOBE sun photometer, an inexpensive individually-produced device which necessitates additional device measurements for each calculation. Development began in 2010 of the Calitoo, a handheld sun photometer for use in the GLOBE program which automates many of the previous measurements necessary for AOT calculation.

Calitoo manual and info found at calitoo.fr

Measurements

AOD measurements for 6 Calitoos were taken at a test site app. 877m SSW from the LaRC CAPABLE site (AERONET). Visibly clear (clouds <10%) days at LaRC, researchers made 3 measurements every 15 minutes (6/3/2014 to 7/25/2014). In total,10,116 unique Calitoo wavelength AODs were measured from a total of 3,372 button clicks. The 3 measurements were averaged to create 1,124 data points. AERONET was being serviced much of 6/2014 and of the 1,124 Calitoo data only 238 were within 7 minutes of an AERONET reading thus comparable.

CAPABLE Site

Test Site

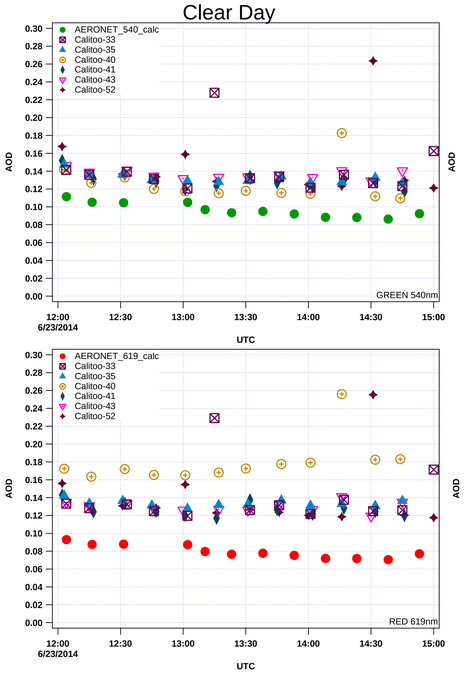
CAPABLE Site Coordinates:
Latitude: 37° 23′ 13.45″ N
Longitude: 76° 23′ 13.38″ W
Elevation: 3 m ASL

The Test Site and the AERONET site at CAPABLE are not only close but have similar environmental conditions as seen here, making for a good comparison location.

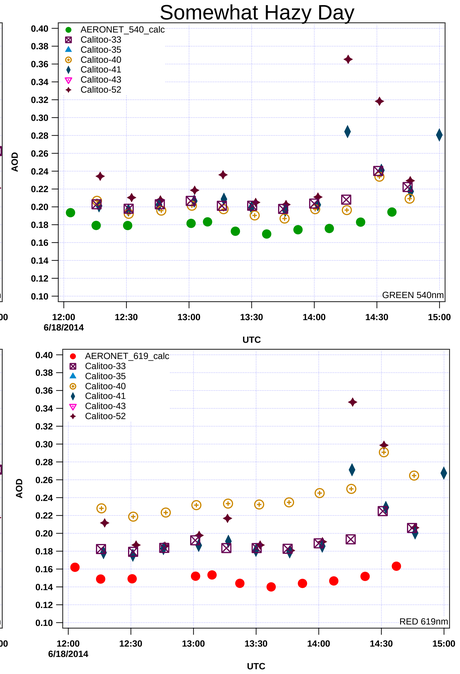
Data Comparisons with AERONET

--The AOD measurements from NASA's Aerosol Robotic Network (AERONET) used in figures (a), (d), and (f) is recorded with a research-grade sun photometer. Much like the GLOBE photometer, it is a remote-sensing passive instrument that takes column measurements.

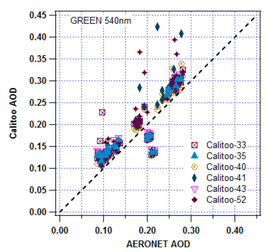
Clear Day



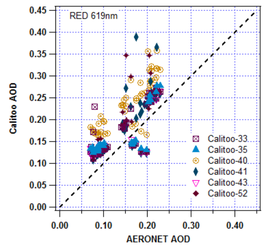
Somewhat Hazy Day



Residual



As these scatter plots show, Calitoo AOD was almost consistently higher than AERONET, in a range of +2 to +6 AOD. Ozone and other factors both internal and external were evaluated and found not to be the cause of this inflation.

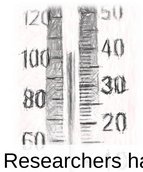


Whereas the GLOBE sun photometer measures at two wavelengths, red (λ625) and green (λ505), Calitoos measure 3 wavelengths including red (λ619), green (λ540), and blue (λ465, not depicted here). Angstrom exponent was applied to AERONET readings at λ675, λ500, and λ400, respectively, for comparison at Calitoo wavelengths. For classroom application, Calitoo data faired favorably when compared with AERONET. The Calitoo wavelength data points trend similarly although 1 of the 6 devices, Calitoo-52 in the data, consistently trended higher and more erratically and another device, Calitoo-40 in the data, consistently trended higher at only λ619, suggesting possible calibration issues. Such issues in 2 of 6 devices pose potential issues in classrooms with only 1 device. Sky condition measurements, compared by a clear and somewhat hazy day, are shown above. With the exception of higher-trending devices, Calitoo measurements show precision but lack accuracy. Adjustments to device calibrations are advised.

Ease of Use and Classroom Suitability

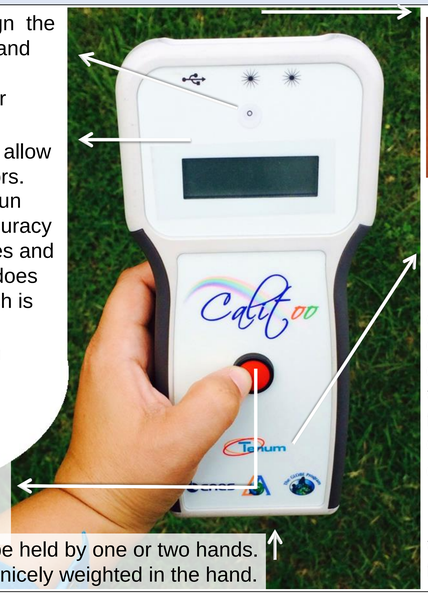
The aperture reading hole used to align the device with the sun is less than 2mm and requires much focus and stability for alignment, a potential pitfall in younger classrooms.

The addition of a backlit screen would allow for greater visibility of readings outdoors.



The similar GLOBE sun photometer loses accuracy with high temperatures and it is possible Calitoo does as well. More research is needed.

Researchers had mixed responses on the single center button. While one admired its simplicity, another responded "…To have a separate on/off switch as well as a separate switch to toggle between the modes (reading and measuring) would make the Calitoo much more user-friendly."



210x100x35mm allow the Calitoo to be held by one or two hands. At 400g (with batteries) the Calitoo is nicely weighted in the hand.

Tenum, Calitoo's manufacturer, responded promptly to any questions.

Calitoo data downloads easily into a .txt file which is convertible thru delineation. Calitoos use decimal commas not decimal points to separate place values though words have been translated to English.

On at least one device there was noticeable overhang of material on both measuring and aperture holes.

Though Tenum suggests placing a piece of tape over the measuring holes this may cause adhesive debris. Researchers did note natural wear on the device altered the aperture visibility in one device and could effect measurements.

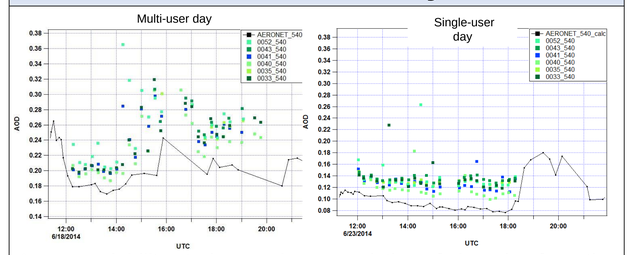
```
Elevation;AOT465;AOT5
0,2991;0,2373;0,2505
0,3043;0,2427;0,2529
0,3022;0,2451;0,2477
```

Calculating AOD

When taking a voltage reading, Calitoo automatically measures the following values and calculates the AOT instantaneously using a variant of the Beer-Lambert Law.

$$I(\lambda)=I_0(\lambda)\cdot\exp(-m(T_a+T_g+T_{NO2}+T_w+T_{O3}+T_r))$$

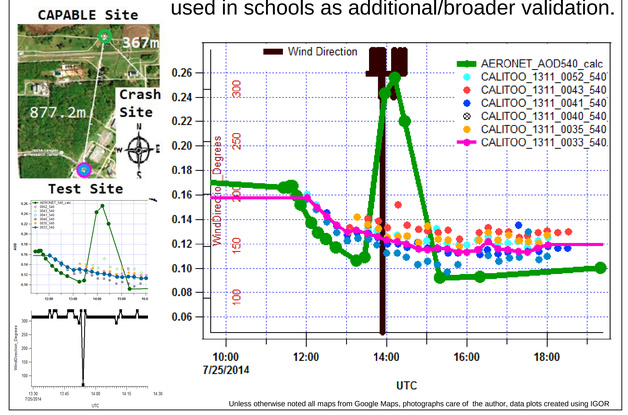
User Variability



A user variability study was done consisting of changing from the random multi-user data collection to a single researcher collecting data using all devices. Precision among the devices is shown in the data to increase with a single user however could also be attributed to experience using the instrument suggesting a long learning period. Among the data, one of three researchers had measurements consistently less precise regardless of device. In a classroom with many students potentially using a single device the likelihood for a loss of precision should be considered.

Catching AERONET Incident

On 7/25/2014 there was a simulated plane crash 367m from AERONET at CAPABLE. Though Calitoo readings were being taken simultaneously and recorded no significant change during the time of the crash, AERONET spiked to .24 AOD at 13:57 UTC. Wind direction, plotted here for the time of the crash, shows wind direction NNW all morning with an abrupt change at 13:54 UTC signaling the crash disruption in AERONET AOD. This data is significant because it shows potential for high-value equipment readings to be globally misrepresentative based on localized events and the benefit of inexpensive portable devices used in schools as additional/broader validation.



Unless otherwise noted all maps from Google Maps, photographs care of the author, data plots created using IGOR

Acknowledgements

The author would like to thank Dr. Margaret Pippin for her guidance and instruction, Mr. Robert Bujosa and Mr. Charles S. Haggard for their invaluable assistance, and Dr. Gary Halvorson for his introduction to atmospheric science along with Sitting Bull College for their support. This work was supported by the Tropospheric Emissions: Monitoring of Pollution (TEMPO) student collaboration, the Long-term Engagement in Authentic Research with NASA (LEARN) project, and the GLOBE program with funding provided through the NASA Science Mission Directorate. This project would not have been possible without the support of the Office of Education at NASA Langley Research Center.